STUDIES IN POTATO DISEASES

IV

POWDERY AND COMMON SCAB OF THE POTATO

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AND

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By D. J. MacLEOD and R. R. HURST

POWDERY SCAB

INTRODUCTION

Seventeen years have elapsed since powdery scab of potatoes was first observed in Canada. In 1913 the first record of this disease on the Continent of North America came from the Dominion Botanist (1) who noted its occurrence on potato tubers collected in Prince Edward Island, Quebec, Nova Scotia and New Brunswick.

Subsequent observations by Dr. J. W. Morse (2) and Dr. J. E. Melhus (3) provided conclusive evidence that the disease had been active for a number of years in widely separated areas of the United States. Records show that powdery scab has been known in Europe since 1841, when the parasite responsible was described by Dr. Wallroth (4) in Germany and five years later it was noticed in Belgium, Norway and Sweden, as well as in practically all of the potato growing sections of the British Isles. Still later it was found in France.

In 1891 it was discovered in Ecuador, which would lead to the supposition that the disease had its origin in South America, the probable home of the potato; a belief further supported by the discovery in 1915 of powdery scab infection on potatoes from Peru and still later from Mexico, although against this, it must be stated that some authorities believe it was introduced into South America on potatoes from Europe.

ECONOMIC IMPORTANCE

Experience has shown that powdery scab is an exceedingly important potato disease requiring a continuance of the aggressive policy adopted by the Dominion Department of Agriculture; a policy which undoubtedly has restricted its spread, not only throughout Canada, but into foreign markets as well. In 1913, the public were made acquainted with the situation by the Dominion Botanist (1) writing as follows: "The disease should by no means be regarded lightly. Severe attacks occur when potatoes are planted year after year on infected land. Where this is practised the result will be potatoes hardly superior in quality to those affected (wart disease). This fact is worthy of notice, especially since, as in the case of canker, no preventive measures have proved of much value."

Experiments and observations at Charlottetown (5) support the belief that climatic conditions may exercise some influence upon the development of this particular disease. Furthermore, we find from a study of the Division of Botany Plant Disease Survey Reports (6) that, although observed in every province except Saskatchewan and Manitoba, powdery scab is not spreading in Canada, nor, to date, has it been responsible for any serious loss. Notwithstanding this

satisfactory condition it is highly important, nevertheless, to appreciate the destructive nature of this disease and more especially as applied to seed potatoes, for infected tubers are not only worthless on the market, but, in addition, their value is much reduced for seeding the next year's crop.

When conditions favour its development powdery scab has a decidedly detrimental effect upon seed stock, particularly during the storage period when the scab spots encourage the entrance of wound parasites, one of the commonest of which is the fungus responsible for *Phoma* rot. This is a secondary disease often associated with powdery scab and is illustrated in figure 3.

SYMPTOMS AND CONTRIBUTING FACTORS

Powdery scab of potatoes is primarily a disease of the tubers, never attacking the plant above ground. In the early stage it appears as small slightly discoloured pimples or blisters, which, when cut open, exhibit a faint tinge of purple. The infected areas or scab spots may be crowded together into patches or scattered over the surface of the potatoes. (Fig. 1). As the disease advances, the pimple-like swellings enlarge, becoming noticeably rough to the touch and breaking up, in the normal course of events, to form the typical circular

Fig. 1.—Three tubers showing powdery scab infection. Left: Pustules forming band across tuber. Centre: Pustules grouped into a patch at the stem-end. Right: Showing how pustules may be isolated. Notice the cavities with the frayed edges. These cavities contain the olive-coloured spore balls.

cavities having frayed edges (fig. 1) and filled with an olive-coloured powdery mass. (Fig. 4). Common scab (fig. 5) on the other hand is characterized by generally considerably larger and more irregular spots which commonly coalesce, and, while sometimes forming shallow cavities, never exhibit the frayed edges and are moreover devoid of the powdery spore mass, the feature from which powdery scab derives its name.

There is a more severe type of powdery scab differing very greatly from the milder form just described. It occurs in moist soil, or, more particularly, when infected seed is used on land which has already produced a crop of potatoes diseased with powdery scab. Under such conditions the symptoms are very striking and take the form of well-defined warts which are roundish and smooth, with a tendency towards irregularity as illustrated in fig. 2.

Fig. 2.—Shows the deformation produced in bad cases of powdery scab. These tubers were from land badly infected and planted with potatoes five years in succession.
(Photographs and legend by H. T. Güssow.)

As mentioned above, experiments and observations have shown that the occurrence of powdery scab is definitely limited by climatic conditions, the requirements for infection being periods of rainfall when the tubers are young,

Fig. 3.—Phoma rot invading the areas infected with powdery scab.

followed by cool weather and rain. These factors, together with poorly drained soil, seem to offer the most favourable conditions for infection which apparently does not occur usually under any other circumstances.

CAUSE

Powdery scab is caused by a parasite, the name of which is *Spongospora subterranea* (Wallr.) Johns. It is a member of a low order of living organisms known as slime-moulds or myxomycetes. While it would serve no useful purpose

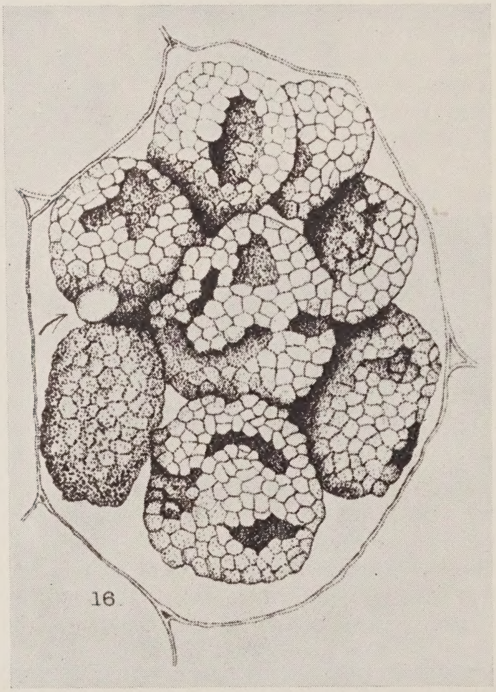

FIG. 4.—Drawing of eight spore balls of the powdery scab organism contained in single cell greatly magnified. Note the spongy appearance. The larger dark areas represent cavities and the small shaded cells the spores. The arrow points to a starch grain.

(After Osborn)

at this time to dwell upon the intricate life history of this organism it is important nevertheless, to understand that the olive-coloured powdery mass occupying the scab cavities is composed of a number of tiny spongy balls which contain exceedingly minute spores, the principal agents responsible for the spread of this disease. Figure 4 illustrates these interesting and important features. When infected potatoes are used for seed these spore balls, becoming liberated in the soil, are capable of infecting the growing crop, and in addition may contaminate the land for several years, thus creating a menace to future potato crops in the area involved.

COMMON SCAB

INTRODUCTION

Common scab is a well known disease of potato tubers, having been recognized for over a century, since the first account of its occurrence was published in 1825. Under favourable conditions it is capable of rapid development, but fortunately it may be prevented to a very satisfactory degree by the careful grower. Common scab occurs in practically every potato growing country of the world, and has a wide distribution in Canada where it is often troublesome in seed producing sections. The parasite is known to live and accumulate in the soil for many years even in the entire absence of potato crops. While this scab does not appear to be detrimental to the eating qualities of potatoes, they are nevertheless rendered unsightly and require heavy peeling. Such potatoes, therefore, are unmarketable. Moreover, the " eyes " may be injured or killed, and thus affected are more predisposed to the attacks of rot producing organisms. Inasmuch as traces of scab disqualify certified seed stock, and, considering Canada's enormous seed potato industry, it is obvious that the occurrence of this disease presents a problem of considerable economic importance.

In full recognition of this undesirable condition the pathologists of the Dominion Laboratories at Charlottetown, Prince Edward Island and Fredericton, New Brunswick, have devoted much time to the experimental study of potato scabs. The results and recommendations derived from these tests are incorporated into this bulletin, and by their faithful application, it is felt that appreciable profit will accrue to those actively associated with the seed potato industry.

SYMPTOMS

Potato tubers are attacked by common scab principally during early tuber development, (7, 10, 23). The first symptoms of the disease appear as minute reddish-brown spots originating at any place on the surface of the potato, but most frequently at the breathing pores (lenticels) where the nature of the cells permits the unobstructed entrance of the parasite. Once started these infected areas become darker, developing rapidly to form the unsightly

Fig. 5.—Common potato scab.

and typical, somewhat circular scab-like areas, occurring singly or in patches, which in the case of heavy infection may involve the entire surface of the potato (fig. 5). Scabby spots, while quickly recognized, may vary somewhat in appearance from roughened shallow depressions to corky protrusions. Barriers of cork, are laid down in concentric ridges by the tuber in an effort to exclude the scab producing germs. The latter are apparent to the careful observer as a thin gray layer immediately beneath a scab spot which, because of its extremely delicate nature, disappears when the potatoes are exposed to light.

CAUSE

Many theories have been advanced to account for the cause of common scab and while they may represent in part contributing factors, nevertheless, it has been established convincingly (8) that it is one of the group of diseases induced by living organisms known as parasites. A study of the available literature on the subject reveals that scab is due to one of these. For a number of years however some doubt existed as to the actual naming of the scab organism. This confusion has been remedied by the Dominion Botanist who wrote (9) concerning the matter as follows:—

"The organism of potato scab properly belongs to this genus (Actinomyces); in consequence, I feel justified in correcting the nomenclature as follows:—

Actinomyces scabies (Thaxter) Güssow."

This therefore, is the accepted name for the organism causing common scab of potatoes. Actinomyces is a specialized organism characterized by the striking habit of forming irregularly branched threads composed of microscopically minute cells (fig. 6). These cells either singly or united, coming into

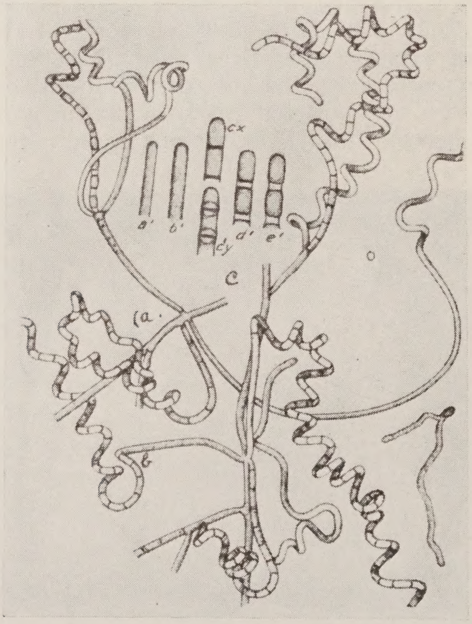

FIG. 6.—Drawing of the common potato scab organism, *Actinomyces scabies,* showing the irregularly branched threads. Over c are shown the successive stages of spore development.

contact with a growing tuber cause infection which develops into the typical scab spots previously described. It is believed that manure is the chief means of spreading this organism while the use of infected potatoes for seed ranks next in importance.

PREDISPOSING FACTORS

Many theories have been advanced as to the development of scab. However, the conditions formerly thought to be the cause of the disease have been proven to be incapable of promoting the disorder in the absence of the causal organism. There are no doubt predisposing factors, viz:—(1) Mechanical irritation; (2) insect and other animal parasites; (3) chemical irritation; (4) excessive moisture. Observations have shown that the disease is influenced by temperature and moisture combined with soil acidity and alkalinity. In the more northerly countries of Europe where the average summer temperature is low there is very little common scab, but in the drier areas of Canada and the United States it occurs very generally. An instance of this tendency has been observed in Prince Edward Island. Thus in 1928 when the growing season was quite dry and warm there was an abundance of scab, whereas in 1927 (a rainy year) scab was rather scarce. According to one authority (10) infected soil, if kept very moist during the growing season, will yield a clean crop. It is known likewise that an alkaline soil is favourable to the scab organism, its growth being suppressed by increased acidity and promoted by increased alkalinity. Using pH as an indication of soil reaction, scab may be abundant in soils at pH 7 (neutral point), while soils at pH 5·2 (slightly acid) produce practically a clean crop of potatoes.

OUTSTANDING DISTINCTIONS BETWEEN POWDERY AND COMMON SCAB

Powdery Scab	Common Scab
Olive-coloured spore-balls in distinct cavities or pockets.	Absence of distinct cavities or pockets and spore-balls but covered with a delicate greyish-white mould immediately after digging which disappears in the presence of air.
Rupturing of pimple-like swellings to form typical frayed or ragged edges of the potato skin.	More or less shallow depressions having edges and bases thickened with irregular concentric layers of corky tissue which may not be raised above the surface of the tuber.
Development favoured by poorly drained soil and cool rainy weather.	Development favoured by light alkaline soil and dry, warm weather.
Frequent occurrence of Phoma or Powdery scab dry rot (*Phoma tuberosa*),	Rots occur but rarely, and Phoma rot never.

CONTROL OF THE SCAB DISEASES

Owing to the fact that powdery and common scab behave similarly in many respects, the remedial measures here outlined—eminently for common scab—are in most cases effective in controlling both scabs. While powdery scab is widely known, outbreaks of this disease in Canada are usually sporadic, so that it may now be considered of only slight importance as a limiting factor in potato production. Control measures are based on present knowledge of the agencies responsible for its occurrence. A thorough study of the life history and behaviour of the causative organism of the disease has contributed largely towards the development of means for destroying the same or suppressing its activities sufficiently to prevent attack upon the host. Where environment influences the formation of scab, practical methods have been devised for modifying, in many instances, the conditions chiefly involved. Natural agencies,

fortunately, in certain localities serve as important factors in limiting the occurrence of the disease. The subject of control in general, resolves itself into the following:

DISEASE FREE SEED

The use of seed potatoes free from scab is quite an important factor in the control of this disease. Growers are assured of such quality only when Certified Extra No. 1 seed potatoes are used. The rigid certification standards enforced by the Dominion Department of Agriculture, allowing only a practical minimum of scab, place at the disposal of purchasers of seed potatoes, a product which is remarkably safe to use for this and many other reasons. Full information concerning Certified Extra No. 1 seed potatoes is set forth in Pamphlet No. 129—New Series—published by the Dominion Department of Agriculture at Ottawa.

RESISTANT VARIETIES

Resistance to scab is determined to an appreciable extent by the thickness of the cork and extreme external layers of the starch parenchyma (11), to which structures this disease is largely confined. Lenticels composed of small, closely compacted cells and partly buried in the skin of the tuber are also associated with resistance to this disease. The true russet types by virtue of possessing the characteristics just referred to, are markedly resistant; the semi-russets slightly resistant; while the thin-skinned varieties appear most susceptible (12). Much more confirmatory evidence must be secured, however, from comparative tests of series of varieties grown under diverse environmental conditions, before any one variety can be adjudged deservedly resistant to this disease.

CROP ROTATION

The continuous cultivation of potatoes in the same soil creates conditions deservedly favourable to the development of scab, regardless of whether the seed used is free from the disease or has been rendered so by disinfection or other means. This is probably due to the fact that the scab organism originally exists in most soils and becomes more and more prevalent by continuous cropping. In consequence, it is necessary, in order to eliminate this phase of the cause of the disease, to practice a definite system of crop rotation, from three to five years between potato crops under normal conditions, or even longer rotations; five to six years if the soil is known to be heavily infected with the scab organism. Grasses, small grains, alfalfa or clover constitute excellent crops for such rotations. Such crops as beet, mangel, turnip, rutabaga (the latter is less so in Western Canada) are susceptible to scab for which reason must be eliminated from rotations intended for the correction of soils for scab disease. It is now recognized that the scab organism may persist for years in the soil independent of any of the common host plants, existing mainly on decaying vegetable matter. There are a number of hosts susceptible to scab but it is not yet clear what rôle certain of these exercise in perpetuating the causative organism.

SOIL CONDITIONS AND TREATMENT

Soil temperature also influences the occurrence of scab. The disease develops most readily at high soil temperatures (70°—75° F) (13) and is suppressed as the soil becomes cooler. This confirms the contention of many practical growers that the disease is most severe during hot seasons and less so when cooler weather

obtains. The influence of soil temperature is an important factor in the reduction of scab in areas where the day temperatures are usually high and the night temperatures generally low.

Soil moisture is also an important factor in the control of scab. The disease is inhibited in soils with high moisture content and develops more readily where drier soils obtain. Cultural practices should be adopted which improve the texture and structure of the soil, favouring the circulation of air, incidently retaining the proper amount of moisture.

While soil temperature and moisture are recognized as contributing factors in the suppression of the activities of the causative organism of scab under natural conditions, the modifying influence of changes in soil reaction is of equal and probably greater value, in that it affords of practical control measures capable of being conveniently applied by the average grower. Owing to the fact that an alkaline soil favours the development of scab, fertilizer elements, soil amendments and other substances which produce an alkaline condition should be used with caution on soils intended for potatoes. If soils used for potatoes require such alkaline substances as lime for correction, they should be applied moderately at another stage in the crop rotation. Similarly, heavy applications of mussel mud and wood ashes, are not advisable unless it is definitely known that the soil is too acid to permit the growth of a satisfactory crop, or is relatively free from the scab organism in an active condition. Tubers infected with scab or peelings from such should not be used for stock feed or mixed with manure intended to be used on potato soils, because the scab organism is capable of passing unharmed through the digestive tract of domestic animals and multiplying in the fresh manure which is a favourable medium for its development. Stable manure should be thoroughly decomposed before the tubers are planted or used with other substances which counteract its alkaline tendency in the fresh condition. Manure which contains wood sawdust or shavings frequently used for bedding should be avoided because these materials also render the soil even more favourable to scab. Nitrate of soda on account of its alkaline tendency should be used cautiously as a source of nitrogen in potato fertilizers. Equal proportions of sulphate of ammonia and nitrate of soda serve as a favourable source of nitrogen for soils infested with the scab organism. The fertilizer ingredients should be combined in the following proportions, which is equivalent to a ton of 4-6-10 mixture: 260 pounds nitrate of soda, 190 pounds sulphate of ammonia, 750 pounds acid phosphate and 400 pounds muriate of potash. In as much as an acid soil is unfavourable to the development of scab the application of substances capable of producing an acid condition when mixed with the soil serve as a practical control for the disease. Turning under clover, alfalfa or other suitable green manuring crops which upon decomposition in the soil produce a slightly acid condition is also an economical and practical way to control scab. This operation should be performed, however, at the close of the growing season, not in the spring. Continued use of large amounts of sulphate of ammonia creates an undersirable acid reaction in the soil, which may render the same unfavourable for the growth of alkali-loving plants such as clover, alfalfa, cabbage and many others, until such unfavourable soil conditions are corrected by the use of lime or other compounds producing an alkaline reaction.

Sulphur, one of the essential food elements of plants has also been recommended as a preventive for scab. The fungicidal action of sulphur is attributed variously to the acid condition produced by the element when it becomes oxidized to sulphuric acid in the soil or to pentathionic acid which is effective as a toxic factor. Either ordinary or inoculated sulphur may be used, the latter is scarcely more effective if any, although it is claimed to be, due to the fact that the ordinary, commercial, granulated form of the element,

is but slowly transformed in the soil into the state required for the production of an acid condition. This, it is said, is particularly true when the sulphofying bacteria in the soil which oxidize the sulphur are inactive or absent (14). The use of inoculated sulphur is claimed to correct this difficulty since it consists of finely ground sulphur to which has been added pure cultures of the sulphofying bacteria to bring about a more rapid oxidation of the element after it has been incorporated with the soil. Sulphur should be applied broadcast or introduced with a grain drill or other suitable equipment any time after the soil is ploughed but previous to the time the potatoes are planted. Sulphur should not be applied in the row with the fertilizer at planting time because injury to both vines and tubers may result. Russetting and cracking of the tubers are characteristics of this type of injury. Table 1 embodies the results of an experiment conducted at Fredericton, N.B., on the effect of inoculated sulphur on the development of common scab. The

TABLE 1—THE EFFECT OF INOCULATED SULPHUR ON THE DEVELOPMENT OF COMMON SCAB*

Rate of application	Disease content			pH values of soil	Total yield per acre
	Free	Slight	Severe		
	%	%	%		bush.
Sulphur, 400 pounds per acre..	23·6	51·79	24·61	5·87	223·0
" 600 " "	28·56	49·95	21·49	5·68	206·7
" 800 " "	30·68	49·81	19·51	5·42	224·0
" 1,200 " "	41·18	39·27	19·55	5·44	223·8
Check (no treatment)........	16·54	49·57	33·89	6·31	215·1

*Soil was light sandy loam.

amount of sulphur required for most effective control is determined to some extent by the severity of scab in former crops. In cases where previous crops were severally attacked upwards of 600 to 800 pounds to the acre may be necessary, while in instances where only slight or moderate amounts of scab occurred, 400 to 600 pounds are ample. If ammonium sulphate is used as a source of nitrogen in the fertilizer, the sulphur should be reduced one-third to one-half and eliminated entirely where scab is only of slight occurrence. Sulphur is more effective as a control for scab on lighter soils than on heavier types and muck soils (15). Perfect control with sulphur has never been obtained on any soil. The results with sulphur on light soils, however, have been sufficiently fruitful to give a profitable crop in most cases. On account of some unexplained residual effects, sulphur also creates harmful conditions in certain soils which render them unfit for growing other crops. In consequence, sulphur should be restricted to soils reacting most favourably to it. A thorough soil analysis should be performed by a capable analyst, before sulphur is applied in large amounts continuously to soils intended for other crops as well as potatoes. A reliable analysis of any soil can be obtained free of charge by submitting samples of the same to the Dominion Chemist, Central Experimental Farm, Ottawa. Before sending samples promiscuously, however, application should be made for instructions how to collect a representative sample. This will save trouble and delay at both ends.

Agricultural gypsum (calcium sulphate) has also been advocated for the control for potato scab. Gypsum has proven useful in our experiments and elsewhere in the prevention of scab on heavy soils (16). Unfavourable results have been obtained, however, with gypsum as a control for the disease on

light soils. There appears, however, to be no appreciable change in soil reaction (acidity and alkalinity) even after as much as 2,000 pounds of gypsum have been applied to average soils. The manner in which the activities of the scab organism are suppressed on certain soils by gypsum is not clearly understood. Soil reaction does not appear to be associated with the mechanism of control. The principal effect of gypsum is probably its action of increasing the available supply of potassium as evidenced by the fact that tubers which have grown in soils treated with this compound; contain more potassium than those receiving no treatment. The fact that gypsum itself supplies an essential plant food (sulphur) and increases the amount of potassium which is even more important, maintains the potato plant in a more healthy condition. It is of interest to note in this connection, that gypsum is a by-product in the formation of acid phosphate (17) which is not removed from the commercial brands of this compound used in chemical fertilizers. Accordingly, every 1,400 pounds of 5-8-7 fertilizer mixture supplies at the same time 350 pounds of gypsum, calculating however, that the acid phosphate contains 50 per cent calcium sulphate. Further confirmatory evidence from experiments conducted on different types of soil must be obtained before gypsum can be definitely recommended or discarded as a suitable control for potato scab. Table 2 includes the results of an experiment conducted at Fredericton, N.B., on the use of gypsum as a control for potato scab on light soil.

TABLE 2—THE EFFECT OF GYPSUM ON THE DEVELOPMENT OF COMMON SCAB*

Rate of application	Disease content			pH† values of soil‡	Total yield per acre
	Free	Slight	Severe		
	%	%	%		bush.
Gypsum, 500 pounds per acre.	72·47	17·97	9·56	6·31	269·3
" 1,000 " " "	68·04	21·42	10·54	6·36	256·4
" 2,000 " " "	74·58	18·0	7·42	6·32	267·8
Limestone, 2,000 lbs. per acre.	51·84	31·37	16·79	6·86	265·7
Check (no treatment)........	75·68	16·07	8·25	6·34	271·6

*Average of three years' results.
†Readings, 1930.
‡Soil was light sandy loam.

SEED TREATMENT*

During the dormancy of the potato tuber, the scab organism is capable of remaining more or less in a resting but perfectly viable condition in the scab spots, awaiting introduction into the soil when the potatoes are planted, to renew attack upon its host returned to active life again. The scab organism when existing on the surface of the tuber can be destroyed by proper disinfection with chemicals. Seed disinfection can be accomplished with safety at any time while the potatoes are in the dormant state, either in the fall, before the tubers are placed in storage or in the spring just prior to planting. Seed treatment can be successfully performed in the fall without injury to the tuber or much

* The whole question of the benefit of potato seed treatment for scab is still a debatable one. Seed treatment does not (and probably cannot) give protection to the crop. The mystery is how experimenters have obtained such striking results in the past with seed treatment. Recently the results are beginning to show up negatively. The only benefit of seed treatment for scab disease results when the soil is not contaminated with the organisms, but where soils are contaminated, this should—and can—be corrected by changing the conditions as suggested by Messrs. McLeod and Hurst, for seed treatment cannot possibly protect the tubers forming several months after planting a treated tuber (H. T. Güssow).

danger of recontamination if precaution is taken not to place treated tubers in containers which previously held untreated potatoes, unless such containers have also been disinfected. Seed treatment, is, however, more conveniently carried out in the spring. Treatment should be performed before sprouting occurs to any extent, to preclude injury to the sensitive sprouts which may incidently retard germination and impair the vigour of the crop produced from such tubers. Tubers from which the sprouts have been removed are more susceptible to injury during the process of disinfection than those in a dormant condition due to the fact that unhealed surfaces permit of readier penetration of the chemicals into sensitive internal tissues. If potatoes are not planted immediately they are treated and cut, the sets should be placed in containers of not more than two bushels capacity and protected from heat above 70° F., as well as from rapid drying. Pouring the tubers from one container to another several times to prevent sticking together is a good practice. Seed treatment should always be performed before the tubers are cut into sets because newly exposed surfaces are more easily injured by chemicals. All cracked, cut, bruised or decomposed tubers should be eliminated from stock intended for disinfection because they are more susceptible to injury than sound tubers. Soaking the tubers in clean water for periods ranging from 3 to 6 hours is beneficial in that particles of soil or dirt are largely removed, which if allowed to come in contact with the disinfectant may impair its effectiveness. Presoaking is also advisable in that saturation of the cells composing the tissues of the eyes or sprouts with water during this process, counteracts the retarding effect on germination by diluting the disinfectant beyond the point of injury as it diffuses into these sensitive tissues (18). Presoaking also tends to increase the efficiency of the disinfectant in that it stimulates dormant forms of disease-producing organisms into greater vegetative activity, thereby rendering them more sensitive to the action of disinfectants. When a soil is heavily infested with scab and conditions therein are conducive to the development of the disease, seed disinfection is of no avail because it only prevents the introduction of the scab organism adhering to the tuber, into the soil, and has slight, if any, suppressing effect on the activities of the organisms already present in the same. When this condition obtains, it becomes necessary to eliminate the organism from the soil as well as the seed by combining the most convenient and efficient seed disinfection methods about to be described with the most applicable of the soil treatments and cultural practices previously referred to. Far too large a number of compounds are recommended for seed disinfection but only a limited number of these find practical application in the treatment of tubers for the control of scab. Among those accorded more general usage are mercuric chloride (corrosive sublimate), formaldehyde (formalin) and—less so—the recently introduced organic mercurials (Semesan, etc.).

CORROSIVE SUBLIMATE

Corrosive sublimate which is the trade or commercial name of mercuric chloride is an exceedingly poisonous substance. It is generally used in the form of dilute solutions, either hot or cold. The powerful bactericidal action of this compound renders it a most effective agent in the control of scab and other tuber-borne diseases. The exact mode of action of the chemical upon disease-producing organism is not thoroughly understood. A profound disadvantage of the use of corrosive sublimate is *its intensely poisonous nature*,* which renders it unsafe in inexperienced hands, both to the worker and to farm stock. Tubers treated with corrosive sublimate, therefore, should be stored

* In cases of accidental poisoning it is vital to promptly secure medical attention. The antidote is white of egg or milk. Barley water or flour and water should be given. Apply heat to abdomen and stimulate freely.

where there is no opportunity of becoming mixed with or mistaken for potatoes intended for stock or human consumption. Corrosive sublimate is sold in tablet, lump and powder form which may be procured from any reliable druggist. The amount required to treat a given quantity of potatoes will vary with the number of tubers, type of containers and degree of soil adhering to the tubers. One part of corrosive sublimate in 1,000 parts of water constitutes a standard and effective solution for ordinary treatments. Expressed in ordinary terms, this is approximately 4 ounces of chemical in 25 (Imperial) gallons of water. When large amounts of tubers require to be treated it is convenient to use a stock solution of the chemical for replenishing or renewing the treating solution. The preparation of a stock solution consists of dissolving 16 ounces of the chemical in 1 gallon of hot water in either a glass, graniteware, or wooden container. Hot water is preferable in that the chemical dissolves more readily at higher temperatures and metallic containers must be avoided because the chemical destroys most metals, incidently impairing its disinfecting properties. After the corrosive sublimate has been dissolved and thoroughly stirred to ensure a uniform solution of the chemical it can be added to the required amount of water in suitable containers for final use. Stock solution of corrosive sublimate should be used immediately because the chemical deteriorates in solution on long standing. Exceedingly cold water should be avoided as the chemical is more inactive at low temperatures. Suitable working temperatures for the cold method range from 45° to 70° F. Rain water is to be preferred to well water because it does not contain certain impurities which impair the disinfecting qualities of the chemical. A suitable place for seed treatment operations should be selected, bearing in mind location of the stored potatoes, water supply and place where the tubers will be maintained after treatment. Many different types of apparatus are used for seed treatment, nearly all of which can be successfully operated by the average grower. Each person should determine, however, the kind of apparatus most applicable, convenient, and available under his conditions. From 25 to 50 gallon barrels are the most accessible containers for holding tubers during seed treatment. If barrels which previously contained oil or compounds capable of reacting with the chemicals are used, they

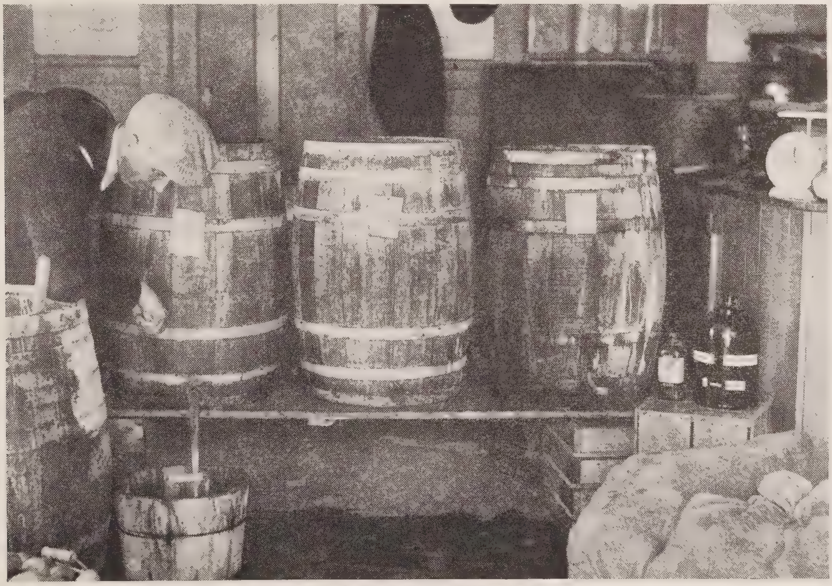

Fig. 7.—Equipment for cold corrosive sublimate method using barrels.

should be thoroughly scrubbed to ensure removal of all of these substances. A convenient arrangement is to have two or more barrels set up on a platform raised about 15 inches from the ground. These barrels should be numbered and provided with drain plugs at the bottom to allow ready removal of the solution from each as required. A hole about 1 inch in diameter bored in the side near the bottom of each barrel serves the purpose. A barrel left on the ground can be used for temporarily containing and mixing the treating solution. Figure 7 shows the equipment necessary for the cold corrosive sublimate method. Assuming that the apparatus required is in readiness for operation, the first step is to take a quart of the stock solution of corrosive sublimate already prepared, which has dissolved in it 4 ounces of chemical, and stir it with a wooden paddle into the barrel remaining on the ground, containing 25 gallons of clean water ranging from 45° to 70° F. Next, the potatoes intended for treatment are placed in barrel numbered 1 which has the drain plug in place. The solution in the mixing barrel is now carefully poured over the tubers until they are completely submerged in the liquid. The time of completion of the treatment should be recorded on a card attached to each barrel. If two or more barrels are employed, the same operation is repeated in each case. An alarm clock or interval timer serves as a useful means of reminding the operator of the completion of each lot of tubers. The potatoes should be treated for 1½ hours. When the tubers have been exposed to the disinfectant a sufficient length of time, the treating solution is drained off by removing the drain plug and caught in a wooden pail or suitable non-metallic container and replaced in the mixing barrel. The treated potatoes are now removed by simply tipping the barrel and dumping the tubers into some other container in which they can be conveyed to a place where they will dry properly. The barrel is now replaced in its former position and filled with a new lot of tubers. The remaining barrels and contents are treated in a similar manner and emptied after the proper lapse of time. The practice of placing the tubers in burlap bags or wire baskets during the process of treatment is objectionable due to the fact that these contain substances which react with the corrosive sublimate and impair

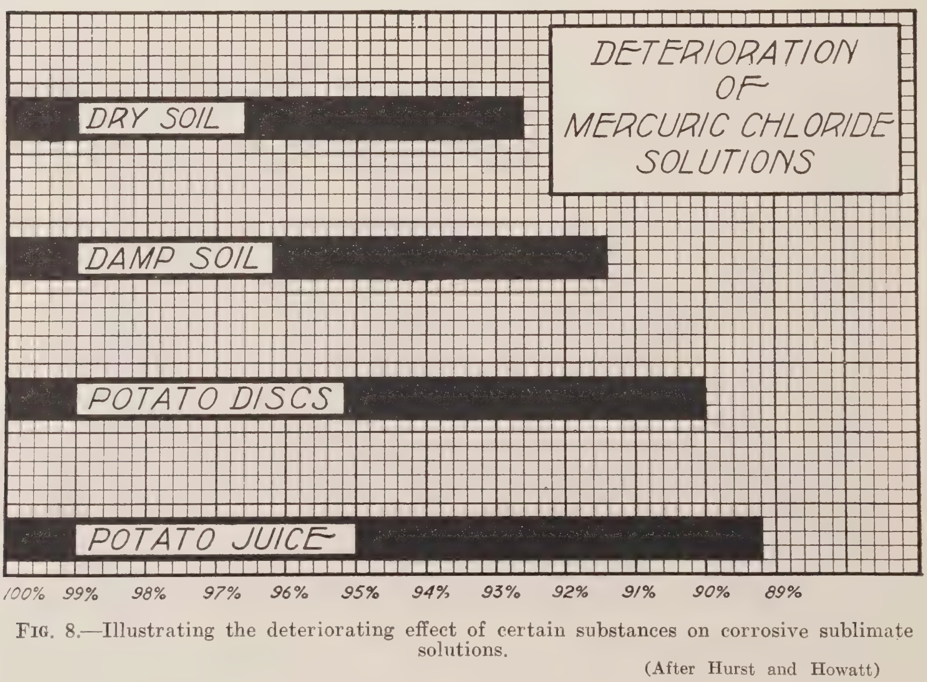

Fig. 8.—Illustrating the deteriorating effect of certain substances on corrosive sublimate solutions.

(After Hurst and Howatt)

its effectiveness. Soil and organic matter from the tubers weakens the corrosive sublimate to a considerable extent. In order to maintain the correct strength of the solution, one-quarter pint of the stock solution, or one-half ounce of the chemical dissolved in about a quart of hot water should be added to the original solution after each lot of 4 bushels has been treated. The original volume of the treating solution should be kept constant. Water must thus be added after each lot is treated to replace that lost in previous treatments. On account of the rapid accumulation of soil and organic matter with continued treatment and deteriorating effect of these on the corrosive sublimate, the solution should be discarded after the fourth consecutive treatment, even though the addition of one-half ounce of chemical has been made after each treatment as recommended (19). Figure 8 illustrates graphically the deteriorating effect of certain substances on corrosive sublimate solutions.

Experiments conducted at the Dominion Field Laboratory of Plant Pathology, at Charlottetown, P.E.I., show that the solution is not effective if used more than 4 times (fig. 9). In other words, the corrosive sublimate added after the fourth treatment is practically wasted and would be better employed towards preparing a new solution. Using 6 to 8 barrels, the services of three

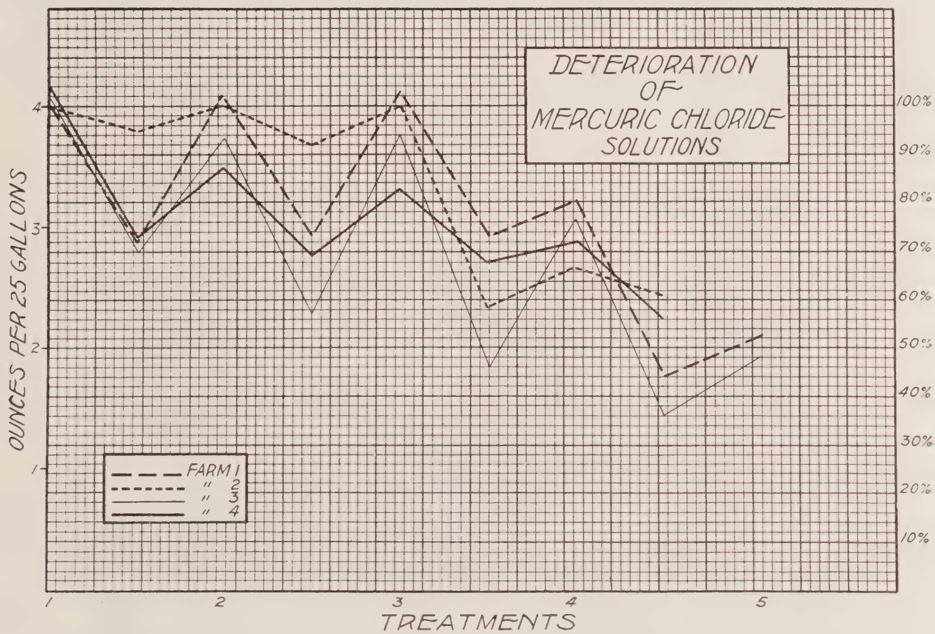

FIG. 9.—Illustrating the failure to compensate for deterioration by adding one-half ounce of corrosive sublimate after the fourth treatment.

(After Hurst and Howatt)

men will be fully occupied attending to treating operations. From 200 to 300 bushels can be treated in a day according to the cold method providing proper conveniences are available. Shorter periods of immersion than $1\frac{1}{2}$ hours in connection with the cold treatment are not effective. While barrels have been suggested as suitable and inexpensive means for holding potatoes during seed treatment, other types of containers can be used successfully. Wooden tanks or cement troughs large enough to accommodate 8 or 10 crates set side by side and deep enough that the solution will cover the tubers when the crates are filled, are now used by certain enterprising growers.

FIG. 10.—Equipment for cold corrosive sublimate method using wooden tank.

(Photo reproduced by kind permission of Mr. Daniel Dean, Nichols, N.Y.)

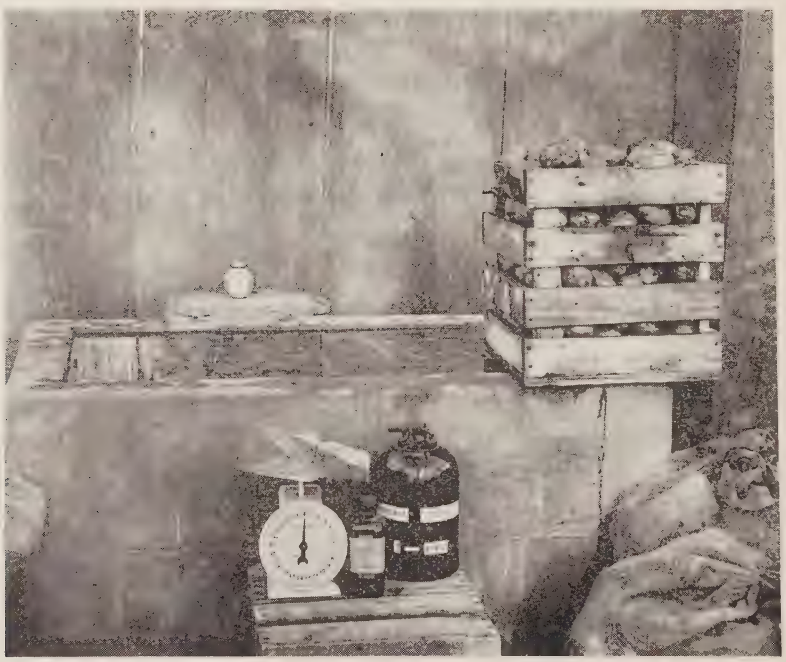

FIG. 11.—Equipment for cold corrosive sublimate method using a concrete tank.

When the temperature of the corrosive sublimate solution is raised to 120° F. and higher, the effectiveness of the treatment is materially increased and the period of exposure obviously decreased. The most suitable range of temperature for treatment under hot conditions is 120° to 126° F. This method is less time consuming than that under cold conditions just described, 2 to 3 minutes being sufficient for each lot of potatoes. Lengthy periods of exposure as in case of the cold method are objectionable not only on account of the time consumed but long contact of the potato with the corrosive sublimate is injurious to the tuber. A wooden tank similar to that shown in figure 10, of about 500 gallons capacity, accommodating from 8 to 10 crates set side by side, heated by means of live steam at 80 pounds pressure from a boiler, is suitable for this purpose. Such a tank should be provided with a false bottom and a space underneath the same at least half as large as that occupied by the crates below. This provides a sufficient volume of water to maintain uniformity and proper range of the high temperatures used in connection with this method. The steam is most conveniently conducted into the tank by means of a rubber hose or an iron pipe of sufficient diameter. A valve in this pipe near the boiler is useful for controlling the supply of steam. The temperature should not be permitted to rise above 128° F., because injury to the tubers rapidly results at this and higher degrees of heat. Also, the temperature should not be lowered beyond 118° F., because the treatment is quite ineffective below this degree of heat at such periods of exposure. A good thermometer, preferably one encased in wood, should be used for temperature determinations. Upwards of 1,000 bushels can be treated in a day by the hot corrosive sublimate method using a 500-gallon tank. This method lends itself readily to community or co-operative treating of potatoes or where large amounts of tubers are handled. Steam from cheese factories, creameries or other sources where suitable boilers are maintained, is frequently utilized where co-operative treating is resorted to. Boilers such as are used in connection with steam threshing outfits or other suitable portable types are more convenient sources of steam for the average grower interested in this method. The steam-coil method is also used to advantage. The details of this method are similar to the direct steam method just described, with the exception that the steam is confined in coils at the bottom or sides of the treating container. There is no appreciable weakening of the solution due to water added by condensation of steam as in the case of the direct steam method. The coils should be covered in order to prevent direct contact with the tubers. The hot corrosive sublimate method has certain disadvantages which do not commend it to the use of the average grower. The apparatus used is quite expensive, working range of temperature, i.e., between effectiveness and injury, is narrow, requiring skilful attention to maintain the same within proper limits. Steam from suitable sources is not readily available for the use of the individual grower. There is no practical method, excepting that utilizing steam, suited to the convenience of the average grower, for heating the solution in containers which do not react with corrosive sublimate. Feed boilers and other types of containers constructed of metal cannot be used for holding corrosive sublimate on account of the deteriorating effect on the chemical. The corrosive sublimate method costs from $1.25 to $1.50 an acre.

FORMALDEHYDE

Formaldehyde is also employed to a considerable extent as a disinfectant for the control of scab and other tuber-borne diseases of the potato. This substance is a gas at ordinary temperatures. It is ordinarily procured from any druggist under the trade name of "Formalin," which contains 40 per cent formaldehyde in water. As a disinfectant it possesses certain features which commend its use commercially. It is not poisonous like corrosive sublimate, and does not

deteriorate when exposed to metallic substances, which renders it possible of being contained in metal vessels. Furthermore, its disinfecting properties are not materially affected by organic matter and soil from the tubers, thereby obviating frequent renewal of the solution as in the case of corrosive sublimate. Formaldehyde dissolves with considerable ease in either hot or cold water. Although formaldehyde appears quite volatile, dilute solutions of the same heated to 125° F., and maintained at this temperature for an hour, showed no appreciable change in strength (20). Moreover, formaldehyde solutions used for treating potatoes left for a month at ordinary outside temperatures, deteriorated but slightly. Formaldehyde emits rather pungent fumes which irritate the mucous membranes of nose and throat, and in common with corrosive sublimate is capable of producing much injury to the tubers if specific directions for treatment are not carried out properly. Pronounced tuber injury due to impurities in the formaldehyde has occurred from time to time. This is attributed to the formation of another form of formaldehyde, known as paraformaldehyde which upon mixing with the soil becomes quite toxic to the plant. Commercial brands of formaldehyde generally contain sufficient alcohol to counteract the formation of this toxic form of the chemical. Pure solutions of formaldehyde are perfectly clear while even traces of paraformaldehyde produce a milkiness or may manifest themselves in the form of sediment if present in large quantities. Precaution should therefore be exercised when purchasing formaldehyde to ensure that the brands obtained contain a minimum of this injurious impurity —it should be as clear as water when bought.

The equipment previously described in connection with the cold and hot corrosive sublimate methods can be used to equal advantage for formaldehyde treatments. The cold formaldehyde has not proven as effective as the cold corrosive sublimate method for scab control in general practice, for which reason it is now rarely employed excepting where small lots of slightly infected potatoes require treatment. One pint of formalin in 25 gallons of water is pre-

Fig. 12.—Equipment for hot formaldehyde method using a feed boiler.
(Photo reproduced by kind permission of
W. W. Hubbard, Fredericton, N.B.)

scribed for the cold method. The hot formaldehyde method is gaining popularity with many growers on account of its inexpensiveness, simplicity of operation and rapidity with which effective treatment can be accomplished. The equipment used in connection with the hot formaldehyde treatment is well suited to the convenience of average growers. This is due in large measure to the fact that metallic containers can be used. The hot formaldehyde is more efficacious than the cold corrosive sublimate method and equally effective and safer than the hot corrosive sublimate treatment. A convenient and simple apparatus for heating the solution is a feed boiler of the type used on many farms (fig. 12). If this type of heater is not available a metal tank heated by means of a fire in a trench underneath is quite suitable. In the case of heaters of the type just described, the temperature of the solution is maintained at the prescribed degree by regulating the draft or by the addition of a cold solution of the same concentration. When a fire is used beneath the tank, a false wooden bottom should be provided for the tank to prevent the tubers from immediate contact with the bottom. The same precaution must be exercised as in case of the hot corrosive sublimate method, to maintain the proper range of temperature—120° to 126° F. Two pints of formalin in 25 gallons of water are prescribed for this treatment. The duration of treatment is 3 minutes. Wire baskets or burlap bags may be used for containing the potatoes while immersed in the formaldehyde solution. Sacks are objectionable, however, in that they do not permit the free circulation of the treating solution among the tubers afforded by more open containers. When steam is used as a source of heat it is necessary to add after every 50 bushels are treated, approximately 1 pint of formalin to compensate for that diluted by the condensed steam (21). There are a number of satisfactory treating machines on the market which can be used successfully in connection with the hot formaldehyde method. These accommodate one or more sacks of tubers at a time. The treating solution is heated in a metal tank by suitable burners using either gasoline or kerosene under low pressure. Most machines are provided with convenient mechanical devices for

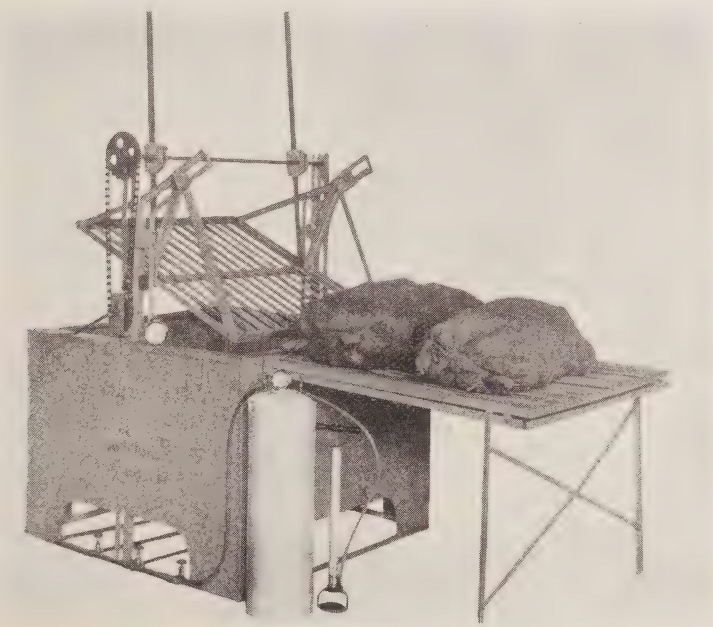

Fig. 13.—Seed treating apparatus for hot formaldehyde method.
(Photo reproduced by kind permission of
Red River Seed Treater Co., Moorhead, Minn.)

manipulating the tubers during the process of treatment. There is no water of condensation added as in case of the direct steam method; hence the solution remains practically constant rendering the cost lower than when steam is used as a source of heat. Other than the expense involved, these mechanical treaters are quite satisfactory.

After immersion according to the hot or cold formaldehyde methods the tubers should be arranged in a pile and covered with tarpaulins, blankets, bags or any other available covers for at least an hour, in order to retain the volatile formaldehyde around the tubers a little longer to ensure more thorough disinfection. After the coverings are removed, the tubers should be permitted to dry thoroughly. The formaldehyde method costs from 50 to 75 cents an acre.

ORGANIC MERCURY COMPOUNDS

During the past fifteen years a number of preparations have been placed on the market for the purpose of seed potato disinfection which contain mercury in combination with certain organic compounds. These organic mercurials attained a high importance as antiseptics. Presumably, on account of their great bactericidal value, the use of certain of these extended from medicine to agriculture. The bactericidal value of the majority of these compounds is of the same order as corrosive sublimate yet they are less poisonous to human beings and domestic animals. Among those recently given attention by the authors are Semesan, Sanoseed, and a number of others, certain of which have yielded favourable results as potato disinfectants. Occasionally, these insoluble compounds contain other substances, usually of an alkaline nature, which possibly aid their disinfecting action by increasing their solubility (22). Organic mercurials do not form a true solution but instead a milky liquid containing suspended particles of the chemical. One important feature of these organic mercurials is that they can be applied in cold form and do not deteriorate when in contact with organic matter and metals, thus dispensing with the expensive equipment usually necessary in connection with the methods just described. Moreover, the action of these compounds is quite rapid, exposing the potatoes momentarily in most cases suffices to coat them with the chemical, which being insoluble does not readily wash off after planting. In this way, the fungicidal action of these compounds is much prolonged. Their general effectiveness, however, is still a matter of controversy. These compounds are also used in the dry form to advantage. Manufacturers of organic mercurials contend that they stimulate plant growth and can be applied to cut as well as whole tubers without causing injury. Experiments conducted by the authors have shown, however, that the use of organic mercurials on cut seed sometimes produced a blackening of the exposed surface giving the seed an objectionable appearance. In view of this fact only uncut seed should be treated until fuller explanation of this phenomenon is obtained. No stimulation of growth was observed by the authors during these tests.

Wire baskets of one bushel capacity are most satisfactory for dip treatments, because they afford easy penetration of the solution and thorough drainage. If this were not the case considerable of the solution would be lost and the expense of the treatment materially increased. Loosely woven wooden baskets or crates can be used to advantage if wire baskets are not available. A half barrel large enough to conveniently accommodate the dipping basket, allowing sufficient clearance to permit easy manipulation, is a suitable container for the dip method. In order to prevent loss of the solution, drain boards should be fitted to the container and properly slanted so that the excess from the treated baskets of tubers will flow back into the half barrel. The amount of solution in the half barrel should be sufficient to cover the potatoes in the basket. A

convenient way to determine the proper amount of solution is to place a basket of potatoes in the treating barrel and pour in enough water to completely cover the tubers. After the basket of tubers is removed, a sufficient amount of disinfectant is added to the water and stirred thoroughly. Usually 1 pound to $2\frac{1}{2}$ gallons is prescribed. Definite instructions regarding the rate of application are usually printed on the containers of these compounds by the manufacturers. It is advisable to prepare the solution at least 24 hours in advance in order to ensure a good suspension of the chemicals. Dipping the tubers momentarily in the solution is sufficient in the case of certain of these compounds but others require a few minutes exposure for effective treatment. The basket of tubers

FIG. 14.—Equipment for seed treatment with organic mercurials.

should be worked up and down several times to ensure the solution reaches each tuber. After the prescribed time for treatment elapses, the tubers are removed and left on the draining board. When the treated tubers have ceased to drip, they should be placed in shallow layers to dry thoroughly. Avoid placing potatoes in deep heaps because the lower tubers are liable to be injured by the failure to dry properly. When large amounts of seed are treated it may be necessary to maintain the initial volume of the solution constant by the addition of stock solutions of the same concentration as the original solution. While organic mercurials do not deteriorate appreciably, large amounts of soil and organic matter from the tubers are liable to impair their effectiveness. Hence, the tubers should be thoroughly washed prior to treatment, as recommended under the corrosive sublimate method. Cost of treatment with organic mercurials ranges from \$1.50 to \$2 an acre.

Table 3 includes the results of tests conducted by the authors with the view to comparing the efficiencies of certain disinfectants in the control of common scab.

TABLE 3—EFFECT OF SEED TREATMENT ON COMMON SCAB

Treatment	Disease content			Germination	Total yield per acre
	Free	Slight	Severe		
	%	%	%	%	bush.
Corrosive sublimate (cold)*..	71·37	14·52	14·11	98·8	202·6
Corrosive sublimate (hot)*...	78·15	16·39	5·46	96·2	196·3
Formalin (cold)*............	71·3	20·25	8·45	99·4	187·2
Formalin (hot)*.............	79·4	13·73	6·87	97·3	204·9
Du Pont Cal. K.†...........	73·19	22·13	4·68	99·6	187·6
Du Bay 664..................	75·74	21·28	2·98	99·0	204·6
Bayer Dip Dust†	89·73	5·81	4·46	99·1	203·7
Improved Semesan Bel†......	99·2	0·4	0·4	99·1	196·4
Semesan Bel.‡..............	65·14	15·59	19·27	99·6	182·3
Sanoseed (1-20)‡	72·43	24·28	32·9	96·2	199·6
Du Bay 694 (1-20)‡.........	73·42	22·52	4·06	99·6	191·8
Du Bay 738‡................	74·02	24·51	1·47	99·8	206·3
Scab free seed untreated*.....	76·05	17·05	6·9	96·4	192·1
Scab infected seed untreated*	52·69	25·75	21·56	94·6	179·6

*Average of three years' results.
†Average of two years' results.
‡Average of one year's results.

The various procedures for seed disinfection just outlined are recommended as general practice for potato growers, who desire guidance in the way of written instruction. In the case of those growers, however, who through practical experience are capable of estimating their own conditions accurately in relation to the essential principles set forth in the foregoing pages, seed treatment may under certain circumstances be dispensed with, without appreciable risk of financial loss. There is no attempt made, however, towards lessening in the mind of any grower the great value of seed treatment where conditions render it eminently indispensible. The matter is merely expressed in this way to enable growers who enjoy fortunate conditions and possess adequate knowledge of the same to exercise their judgment intelligently on the subject of seed treatment in order to achieve best results at a minimum effort and expense.

Practical control of the diseases described in this publication can be accomplished in most cases if the grower having acquainted himself with the essential principles of plant protection set forth in these pages, intelligently applies these principles, singly or in combination, to his own particular or local conditions.

SUMMARY OF CONTROL MEASURES

The exclusive use of seed potatoes free from scab is an important factor in the control of the disease.

None of the commercial varieties of potatoes grown in Canada are sufficiently resistant to scab to warrant their use for control of the disease.

Continuous cultivation of potatoes in the same soil creates conditions conducive to the development of potato scab.

A definite system of crop rotation is essential in order to correct soils heavily infested with scab. Beet, mangel, turnip and rutabaga should be eliminated from such rotations because they serve as carriers of the causative organism of the disease from season to season.

Green manuring with clover, alfalfa and other leguminous crops renders the soil unfavourable to the development of scab.

Scab develops most readily when the soil temperature ranges from 70° to 75° F. and is suppressed at lower soil temperatures.

Soils with high moisture content inhibit the disease while dry soils are favourable to its development. Cultural practices should be adopted which improve the moisture holding capacity of the soil.

Acid soils are unfavourable to the formation of scab and alkaline soils favour its development. Lime, wood ashes, mussel mud, wood sawdust and shavings and fresh stable manure should not be applied to soils intended for potatoes on account of their alkaline nature.

A suitable fertilizer for scab infected soils consists of 260 pounds nitrate of soda, 190 pounds of sulphate of ammonia, 750 pounds acid phosphate and 400 pounds muriate of potash which is equivalent to a ton of 4-6-10 mixture.

Tubers infected with scab or peelings from such should not be used for stock feed because the scab organism is capable of passing unharmed through the digestive tract of animals and contaminating the manure which may be used subsequently on soils used for potatoes.

Sulphur at the rate of 400 to 800 pounds per acre is useful as a preventive for scab on light soils.

Agricultural gypsum has given fair control of scab on heavy soils.

When a soil is relatively free from scab, seed treatment is useful for destroying virulent forms of the scab organism on the tubers. Cold corrosive sublimate, hot formaldehyde and organic mercurial treatments are the most effective, economical and convenient methods for the average grower. Corrosive sublimate must be kept in wooden or earthernware containers. Treatment consists of leaving the tubers in a solution containing 4 ounces of corrosive sublimate in 25 gallons of water for 1½ hours, at temperatures ranging from 45° to 70° F. One-half ounce of chemical must be added after each treatment and the entire solution renewed when the fourth treatment is completed. Formaldehyde can be held and heated in any suitable type of container. The treating solution should contain 2 pints of formalin in 25 gallons of water. Period of treatment is 3 minutes at temperatures ranging from 120° to 126° F. Instructions for using organic mercurials are outlined on the containers by the manufacturers.

Most effective control of scab is achieved by combining seed treatment with cultural practices intended for the correction of soil conditions conducive to the development of scab and using Certified Extra No. 1 seed potatoes which are relatively free from the disease and sufficiently vigorous to withstand successfully attacks of disease producing organisms existing in the soil.

Remedial measures outlined for common scab apply in most cases for the prevention of powdery scab.

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